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TECHNICAL MEMORANDUMS
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 931

TESTING OF HIGH-OCTANE FUELS
IN THE SINGLE-CYLINDER AIRPLANE ENGINE

By Fritz Seeber

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TESTING OF HIGH-OCTANE FUELS IN THE SINGLE-CYLINDER AIRPLANE ENGINE*

By Fritz Seeber

One of the most important properties of aviation fuels for spark-ignition engines is their knock rating. The CFR engine tests of fuels of 87 octane and above does not always correspond entirely to the actual behavior of these fuels in the airplane engine. A method was therefore developed which, in contrast to the octane-number determination, permits a testing of the fuel under various temperature and fuel-mixture conditions.

I. PRESENT STATE OF KNOCK RATING OF FUELS IN THE CFR ENGINE

The relative knock tendency of aviation fuels, expressed in terms of octane number is almost exclusively determined by the CFR engine and, more recently, also by the I.G. test apparatus, in Germany. In both engines the fuel is brought to the knocking state by varying the compression ratio. The knock intensity, which must be controlled in these tests, is by common agreement, measured by the reading of the so-called "knock meter" (50 to 60 divisions).

The knock characteristics of the fuel to be tested are compared with those of mixtures of reference fuels in order to exclude the particular conditions of the test engine. By reference fuel is meant one that, on account of its constant characteristics, is employed for the comparison of the performance of various fuels. The following reference fuels are employed:

1. Primary fuels; isooctane and n-heptane;
2. Secondary fuels; pure benzene and synthetic benzine.

In Germany, aviation fuels are tested by the CFR- or I.G.-engine tests (reference 1). The test conditions for these two procedures differ only slightly.

*"Prüfung hochklopfester Kraftstoffe im Flugmotoren-Einzylinder." Luftfahrtforschung, vol. 16, no. 1, Jan. 10, 1939, pp. 18-20.

Although in most of the countries of the world the standardized CFR-engine method is used for testing aviation fuels, no agreement has been reached on an internationally recognized test procedure. The officially recognized procedures in the various countries at the present time are the following:

Germany: CFR-engine method, $n = 900$ r.p.m.; mixture preheating, 1500°C .

England and France: Modified CFR-engine method, $n = 900$ r.p.m.; mixture preheating, 1270°C .

Italy: CFR research method, $n = 600$ r.p.m.; no mixture preheating.

U.S.A.: U.S. Army Air Corps method; $n = 1,200$ r.p.m., no mixture preheating.

The large number of the test procedures at present employed with the CFR engine is an indication of the uncertainty with which the results obtained in the test engine are to be applied to the airplane engine (references 2 and 3). These difficulties became particularly evident when aviation fuels of 87 octane and above were developed.

II. CRITICISM OF THE OCTANE NUMBER AND NEED

FOR THE DEVELOPMENT OF NEW TEST PROCEDURES

In the course of development, it was found that the present method of octane-number determination in the CFR engine, that is, the testing of the characteristics of a fuel under definite conditions, is not sufficient to predict the actual behavior of the fuel in the airplane engine. The determination of the octane number is subject to the following defects:

1. The knock rating is determined only under a single intake or mixture temperature, so that the temperature sensitivity of a fuel is not determined. If, for example, the octane number of an aviation gasoline is determined at various mixture temperatures, other conditions of the CFR-engine procedure remaining the same, there are obtained the following values:

Mixture temperature	Octane number
150° C.	86.9
127° C.	87.4
30° C.	92.1

2. The mixture strength is regulated only for the most intense knocking condition; this occurs, according to tests, at an excess air ratio of approximately 5 percent ($\lambda = 1.05$). This ratio does not, however, correspond to conditions under flight operation. If, for example, the octane number of an 87-octane aviation fuel is determined by the CFR-engine procedure at various excess air ratios and the results compared with those for the primary or secondary fuels under the same conditions, it is found (see fig. 1) that the octane number also in this case gives insufficient information as to the actual behavior of a fuel at the mixture ratios for take-off and cruising (reference 4).
3. The carrying out of the comparison tests occurs under the condition of very intense knock. This condition does not, however, correspond to that occurring in the aircraft engine. Because of the the lack of a simple, reliable indicator, which would enable the determination of any desired knock intensity, incipient knock is the most suitable basis of comparison because it can be most reliably determined in the test engine. According to results obtained thus far, incipient knock can best be determined by ear although indicators are coming more into use (reference 10).
4. The temperature sensitivity of the reference fuel is different from that of the engine fuel so that the application of such reference fuels does not represent the true conditions in the highly heat-stressed aircraft engines of today (fig. 1).

The above-listed defects confirm the view that it is not possible with the present octane number determination in the CFR engine to obtain complete information as to the behavior of a fuel in an aircraft engine.

The need for testing aviation fuels in the CFR engine from newer viewpoints was clearly brought out at the ISA Air Transport session in Berlin, June 1938, in the discussion on fuels. The German proposals (reference 8) particularly required a testing at various mixture temperatures (50°, 100°, 150° C.) and at practically occurring mixture ratios. Furthermore, in addition to the octane number, the determination of the permissible compression ratio or the power at start of knock seems desirable. These proposals were agreed upon by the French, Italians, and others.

These results as well as those, for example, obtained in England on the Bristol-Pegasus single-cylinder engines that took into account the conditions for take-off and cruising all indicate the necessity for carrying out the knock tests under varied conditions.

In order to be able to test better the applicability of fuels in high-compression and/or supercharged airplane engines, new evaluating scales were proposed. Thus Boerlage recommended the allowable boost at the start of knock (reference 5); Evans, Dodd, and Garner, the maximum measurable combustion pressure (reference 6); and M. Serruys, the supercharge power under definite conditions (reference 7). The incipient knock in all these procedures is determined by ear.

III. TESTING OF AVIATION FUELS FOR THEIR ABILITY TO

TAKE A BOOST LOAD

Following the proposal of Boerlage (reference 5), a fuel-test procedure was developed in the DVL that makes use of the permissible boost as a means of rating fuels. This method appeared particularly promising because the behavior of an aviation fuel in the engine can be directly tested in the airplane single-cylinder engine. Since the permissible boost is the only variable, it is possible to test the fuel in any airplane single-cylinder engine at definite conditions.

In these tests the first audible knock is chosen as a measure of the knock intensity. In this connection, it may be mentioned that, according to the view of E. L. Bass, a skilled observer can determine the knock in a single-

cylinder engine long before it can be indicated by any temperature rise in the cylinder barrel or head with the most sensitive thermoelement.

For checking the engine condition as well as the tester's observations, it is advisable each time before the start of the boost-ratio tests to employ a leaded comparison benzine. In order to avoid fluctuation of the quality of the comparison fuel, it is recommended to keep a large quantity of it always in stock.

Before conducting any test, the elementary analysis of the fuel must be known. From the percent composition of C, H₂, and O₂, the air required is computed. The experimenter thus knows the theoretical air required (L₀), the specific weight (γ), and the air pressure (B₀). To facilitate the test procedure, all the constant test values may be combined into a single constant C. It is thus possible without much computation to determine the actual air-excess ratio (λ). The formula then to be applied for the fuel test is

$$\lambda = C \frac{t_B}{t_L}$$

where t_B is the time of the measured fuel quantity in seconds

and t_L , that of the required air quantity.

The excess-air ratio can be determined quickly and accurately with the DVL exhaust-gas apparatus (reference 9).

The test conditions to be maintained constant for a BMW-132 airplane engine cylinder are the following:

Rotational speed. 1600 r.p.m.

Throttle setting. Full throttle

Ignition. Best output at $\lambda = 0.7, 0.9, 1.1$ at no-knock operation

Mixture ratio Range of λ from 0.7 to 1.3

Intake air temperature 35°, 80°, and 130° C.

Start of knock is determined by ear.

The other test data, as compression, cooling-air pressure, etc., are determined by the particular test-engine design.

In order to bring out the value of the boost-ratio method of testing of an aviation fuel comparison is made with the CFR-engine-test procedure for a fuel of octane number 87 and the results of such a test are reproduced in figure 2. The test, which was carried out under the above-mentioned conditions, shows, in contrast to the single-point evaluation of the octane number, the strong dependence of the fuel on the intake-air temperature and mixture ratio. The measurement of the mean combustion-chamber temperature would also be of considerable value in this test.

IV. SUMMARY

The engine-test procedure described is intended to give a more comprehensive determination of the knock rating of fuels. The determination of the effect of the temperature and mixture ratio on the fuel characteristics is a valuable extension of the fuel-testing procedure.

Translation by S. Reiss,
National Advisory Committee
for Aeronautics.

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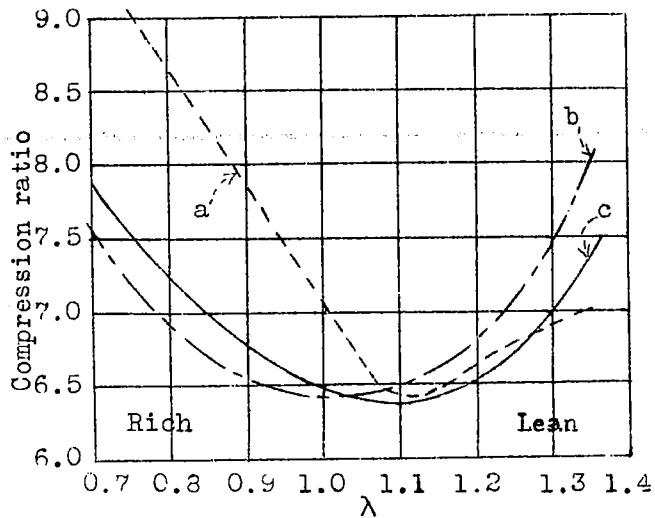


Figure 1.- Knock rating at various air excess ratios.

(a) Leaded aviation benzine, 86.5 Octane.

(b) Isooctane/n - Heptane, 87 Octane.

(c) Mixture of benzine and benzene (B.W. 74), 87 Octane.

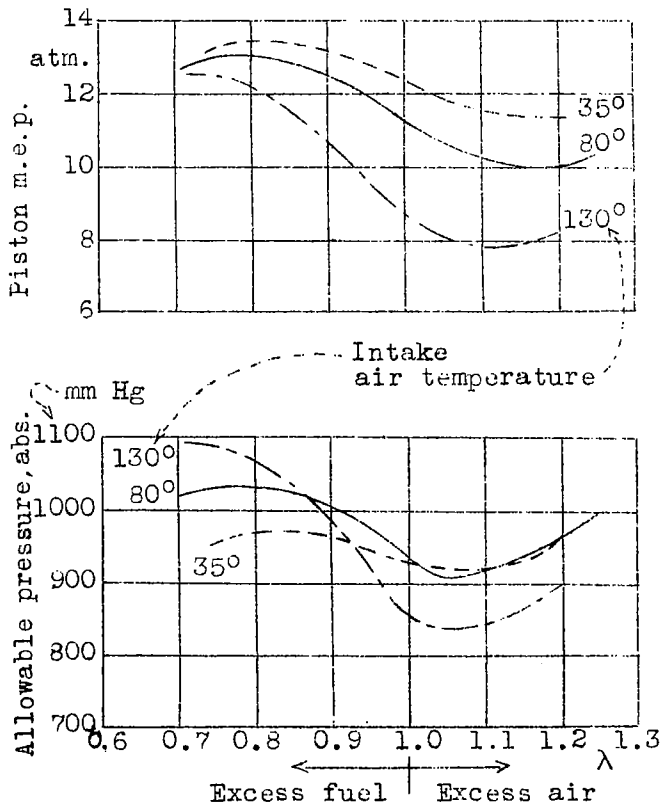


Figure 2.- Test of 87 Octane fuel for allowable boost ratio in single cylinder engine.

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